Variability in roadbase layer properties conducting indirect tensile test

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CONDUCTING INDIRECT TENSILE TEST

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Abstract. Knowledge of variabilities in the properties of asphalt pavement layers is valuable in the structural evaluation of pavements. Mix composition and construction procedure influence the mechanical properties of bituminous layers. Fatigue and stiffness characteristics are two of the most important parameters in input data to pavement evaluation models. In this study, more than 300 cores from 15 test sections were drilled from roadbase layers for determining mix composition, fatigue and stiffness properties. These cores have been tested at different temperatures when conducting the Indirect Tensile Test (ITT). The ITT, which is probably most suitable for examining specimens from pavement layers, has proved to be sufficiently accurate for routine use, such as determination of mix properties, and also in quality control. A good correlation has been found between laboratory based and field based fatigue curves for the roadbase mix.

Statistical fatigue relationships based on the laboratory measurements are also presented and the effects of the variabilities in the mix properties are illustrated. It is hoped that knowledge of the characteristics of bituminous pavement layers with their variations and the use of ITT in routine measurements may contribute to further utilization of pavement evaluation models by road engineers.

Keywords: Bituminous roadbase layer, Indirect tensile test, Resilient modulus, Fatigue strength.

BACKGROUND

The pavement layers are exposed to different types of stresses and strains during wheel passage. These stresses and strains cause a variety of damage in the pavement, such as longitudinal and transversal cracks in the pavement surface. The longitudinal and transversal cracks in the wheel paths are probably induced by the transversal and longitudinal strains respectively. The question is: Which type of cracks appear first? In the Swedish structures, it is believed that the longitudinal cracks in the wheel paths become visible first (Figure 1).

Figure 1. Longitudinal cracks in the wheel path

Therefore, fatigue damage to pavements is believed to be caused by transversal strains at the bottom of bituminous layers. Consequently, the transversal strains are more deleterious than the longitudinal strains under the same loading conditions.
The development of the longitudinal and transversal strains measured at the bottom of the bituminous layers is reported, by Huhtala et al. (1990), among other, see Figure 2. A similar development is calculated by VEROAD (Hopman 1996).

According to Huhtala et al. (1990), the transversal strains are usually 1.1 to 1.5 times greater than the longitudinal strains under the same loading conditions. The longitudinal strain signal shows compression first, then tension and after that compression again. After the wheel passage, the strain will be zero (no permanent deformation). However, the transversal strain signal shows only tension, which slowly decreases to zero. In certain cases, the strain signal could take more than half an hour to return to zero. Also the loading time of the transversal signal is much longer than the loading time of the longitudinal signal.

Comparing the damage effect of the longitudinal and transversal strains with respect to fatigue cracking, the transversal strain is larger in magnitude and loading time. The compression part of the longitudinal strain might create a strengthening effect against cracking. Thus the transversal strains are more destructive than the longitudinal strains and this is probably the reason why the longitudinal cracks are usually observed first on the pavement surface. For this reason, the transversal strain signal should be simulated when studying fatigue properties in the laboratory.

INDIRECT TENSILE TEST (ITT)

Different types of test methods have been used when studying stiffness and fatigue properties of bituminous mixes. Figure 3 shows test methods which are frequently used nowadays.

The problem is: Which method and procedure are most suitable for characterizing
bituminous materials? The choice of the test method depends on the purpose of the specific work, discussed elsewhere (Said 1995). The limits of the test methods illustrated in Figure 3 are also mentioned in the previous reference. In this work, ITT has been used for measuring the stiffness and fatigue properties of roadbase material. The greatest disadvantage of ITT is the accuracy of the stress distribution, which is only valid under ideal elastic conditions (Brown 1978). Therefore, the method should not be used at temperatures greater than about 20°C (Sousa et al. 1991). Furthermore, the Poisson’s ratio must be assumed for the determination of strain across a horizontal diameter. The great advantages of ITT (Kennedy 1977, Pell 1987, Cooper et al. 1991, 1993) are its simplicity and quickness. Cylindrical specimens are used which are relatively easy to core from the road layer. Thus, ITT could be used in routine measurements. The deformation signal formed from ITT is shown in Figure 4. It is comparable to the transversal strain signal form measured during a vehicle passage (see Figure 2). Only tension is present and this decreases slowly to zero.

As mentioned above, the cracking distress is usually longitudinal in the wheel paths and should be related to transversal strains. The fatigue properties of asphalt materials investig-
EXPERIMENTAL INVESTIGATION

More than 300 cores with a diameter of 100 mm were drilled from roadbase layers on 15 test sections when new, and used in laboratory tests. Tests included determination of mix composition, layer thicknesses, fatigue and resilient modulus properties. Eleven of these test sections have been under observation for almost ten years in order to develop a field-based asphalt fatigue criterion applicable to the typical bitumen roadbases in Sweden. Development of distresses in the road sections is followed by FWD measurements for calculating tensile strain at the bottom of roadbase layers, in addition to traffic counts, pavement distress surveys and other investigations. For further details, see work reported by Djjär (1990, 1993, 1996). The field-based criterion is used here to validate the laboratory-based fatigue criterion (discussed later).

Mix composition. The recipe for the mix from roadbase layers should meet the specifications and guidelines for road construction (Swedish Road Administration BYA 84). The bitumen type is B180 and the bitumen content is 3.7 to 4.2 per cent by weight. The aggregate size limits of the grading curve (AG 25) are shown in Figure 7. The maximum aggregate size is 25 mm and the air void content should be 5-10 per cent.

The differences between the grading curves of the test sections are small. See Figure 7.

![Figure 7. Size limits for the roadbase mix AG 25](image-url)

Variations in the mix composition within and between roadbase layers are illustrated together in Figure 8 by frequency distribution diagrams of void content, binder content, void filled with bitumen, voids in mineral aggregate and viscosity of recovered binder. All variables are out of specification limits for the AG 25 mix.

The variations in mix composition should significantly influence the properties of bituminous mixes (Brown 1995). Consequently, these should be checked and taken into consideration when analyzing pavement performance (Molenaar 1995).
Resilient modulus. The resilient modulus was performed on cured specimens at different temperatures. Figure 9 shows the resilient modulus of individual specimens at different temperatures and an exponential regression relationship. The variation in the results is expected due to the variations within and between the mix compositions illustrated in Figure 8.

Figure 9. Variation in resilient modulus of individual specimens, mix AG25

Figure 10 presents the average of the resilient modulus of each test section at various temperatures. Each curve represents a test section. The variation in the modulus between test sections is relatively high and should be taken into consideration when predicting pavement performance. It is believed that the variation in the properties of roadbase layers is primarily due to the wide limits of the mix specification.

Figure 10. Relationships between resilient modulus and temperature in Test Sections
It should also be mentioned that the age of the specimens when tested was between 4 months and 3 years. The variations in the results must be affected by the difference in the age of specimens when tested.

Results presented in Figure 10 have been analyzed statistically. The regression relationship between resilient modulus and temperature for the roadbase mix AG 25 is presented in Figure 11. The 90 per cent confidence and prognosis bands are also illustrated. With a 90 per cent probability, the modulus of any individual road section of roadbase layer, mix type AG 25, will be within the prognosis band. Knowledge of the variations in the resilient modulus of pavement layers is useful for quality assurance and evaluation of pavement performance.

The variability in the properties of asphalt pavement layers indicates the importance of the determination of the properties of existing asphalt pavement layers for use in performance evaluation.

Fatigue properties. Fatigue tests were performed on core specimens from roadbase layers after determination of resilient modulus. Fatigue results on specimens from eleven test sections were used for comparison between laboratory and field based fatigue curves. ITT with constant-stress mode has been conducted at two temperatures: +4°C and +15°C. A cylindrical specimen is subjected to a periodically repeated load with 0.1 sec loading time and 1.4 sec unloading time. The initial strain of the fatigue tests was planned to be in the range of 100 to 400 με because the tensile strains at the bottom of roadbase layers from test sections varied between 100 to 350 με according to Djärf (1996). The fatigue properties are represented by the correlation between the initial strain and the number of load applications at failure. The initial strain used here has been found from total deformation. The total deformation, which is the maximum deformation under a loading period, is composed of resilient and permanent deformation illustrated in Figure 12.

The method of determining initial strain could give rise to contradictory conclusions when expressing the results by strain–number of applications relationships with regard to temperature (Ruth & Olson 1977, Kim, Khosla & Kim 1991, Djärf & Said 1993).

Figures 13 and 14 present relationships between initial total strain and number of load applications to failure. The cores from roadbase layers on the eleven test sections were tested at two temperatures, +4°C and +15°C.

The statistical analysis for each test section has shown the significant effect of temperature at the 5 per cent level for all tested sections.
The variations in the fatigue results were expected, due to a high variation within and between test sections as discussed earlier. On the other hand, the results represent the real field conditions. The variation in the fatigue result is of the same order as the variation in the fatigue life in the field (Djärf and Said 1993).

In order to quantify the effect of mix variability in roadbase mix type AG 25 and for the purpose of validating the fatigue results on cored specimens, an investigation on laboratory compacted specimens was planned. Specimens with different recipes but within the limits of specifications of the roadbase mix (AG 25) were manufactured by a gyratory compactor.

Figure 15 shows the effect of void content on fatigue strength of the mix AG 25. The variation in the void content is produced by using different compaction levels. The variation in fatigue resistance could be more than 100 per cent, illustrated in Figure 15, depending on the void content. These results demonstrate the cause of the high variability in the properties of specimens taken from roadbase layers.

The effect of temperature has also been found in gyratory compacted specimens for the AG 25 mix. Only seven specimens per temperature have been tested so far. The tendency of the effect of temperature, shown in Figure 16, is almost the same as for the cores from the test sections presented in Figures 13 and 14. The effect of temperature is fairly small. This is probably due to the poor binder content in the roadbase mix.
For the field based relation, the strains at +10°C are calculated from deflection bowls measured by FWD in the autumn of the first and second year after opening to traffic. The number of load applications which is equivalent to 100 kN single axle loads is determined from vehicle classification traffic counts. The failure of a test road judged by manual distress identification and thereafter the fatigue life is determined. The field and laboratory fatigue relationships are thus developed independently.

The slopes of the field and laboratory based relations are 2.4 and 2.9 respectively with a shift factor of about 10 (at 200 με) depending on the level of strain. In general, the fatigue life relationship produced in the laboratory is in agreement with the field criterion and it is concluded that ITT is sufficiently accurate for routine use.

For practical use, a statistical predictive equation for the fatigue life of roadbase mix is presented:

\[
\log N_f = 18 - 3.56 \log \varepsilon - 1.79 \log M_R + 0.023 \text{VFB}
\]

where

- \( N_f \) = no. of load applications to failure
- \( \varepsilon \) = horizontal tensile strain in με
- \( M_R \) = resilient modulus in MPa
- VFB = void filled with bitumen in percent

A comparison between measured and predicted fatigue life is shown in Figure 18. More than 300 cores from 15 test sections have been tested. The coefficient of determination (R²) is 0.88. The 90 per cent prognosis limits, which are useable for prediction of pavement performance, are also illustrated.
CONCLUSIONS

- There are many variations in the mix composition of roadbase layers, which gives rise to variabilities in the properties of roadbase layers, such as resilient modulus and fatigue strength. These variabilities should be taken into consideration for a better performance prediction.
- Good agreement has been found between laboratory and field criteria, with a shift factor of 10.
- The indirect tensile test, which is relatively simple, rapid to perform and makes use of cylindrical specimens, is also sufficiently accurate for routine use.

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Statens väg- och transportforskningsinstitut (VTI) har kompetens och laboratorier för kvalificerade forskningsuppdrag inom transporter och samhällesekonomi, trafiksäkerhet, fordon, miljö samt för byggande, drift och underhåll av vägar och järnvägar.

The Swedish National Road and Transport Research Institute (VTI) has laboratories and know-how for advanced research commissions in transport and welfare economics, road safety, vehicles and the environment. It also has research capabilities for the construction, operation and maintenance of roads and railways.

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